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A NEW COMPUTER APPROACH TO MIXED FEATURE
CLASSIFICATION FOR FORESTRY APPLICATION

Job Order 75-315

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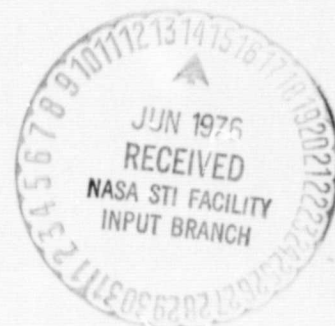
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Lockheed Electronics Company, Inc.
Aerospace Systems Division
Houston, Texas

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For

Earth Observations Division



National Aeronautics and Space Administration
LYNDON B. JOHNSON SPACE CENTER

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April 1976

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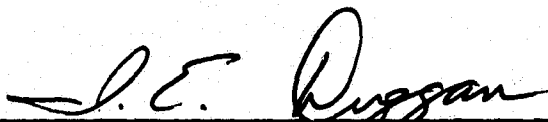
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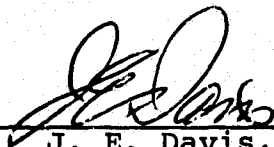


E. P. Kan, Principal Scientist

APPROVED BY



I. E. Duggan, Supervisor
Forestry Applications Section



J. E. Davis, Manager
Earth Observations Exploratory Studies Department

Prepared By

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For

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13. ABSTRACT

Theory and application of a new computer approach for mapping mixed forest features (i.e., types, classes) from computer classification maps are presented. Because standard statistical pattern recognition techniques fail to detect mixed features in U.S. Forest Service defined mixed stands, a new approach is proposed by which mixed features such as mixed softwood/hardwood stands are treated as admixtures of softwood areas and hardwood areas. Large-area mixed features are identified and small-area features neglected when the nominal size of a mixed feature can be specified. At the same time, the computer program merges small isolated areas into the surrounding areas. This approach is accomplished by the iterative manipulation of the postprocessing algorithm that eliminates small connected sets. For a forestry application, computer-classified Land Satellite multispectral scanner data of the Sam Houston National Forest were used to demonstrate the proposed approach. The new technique was verified to be successful in cleaning the salt-and-pepper appearance of multiclass classification maps and in mapping those mixed softwood/hardwood areas that were admixtures of softwood areas and hardwood areas. However, for that particular application, the computer-mapped mixed areas matched very poorly with the ground truth because of inadequate resolution and inappropriate definition of mixed features for Land Satellite data analysis.

14. SUBJECT TERMS

mixed timber stand

stand mapping

mixed feature classification

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smoothing

computer data processing

pattern recognition

connected sets

PREFACE

The author acknowledges the contributions of the three following colleagues at Lockheed Electronics Company, Inc., Aerospace Systems Division, Houston, Texas. Mr. J. K. Lo contributed the original idea and programmed the iterative approach described in this paper. Mr. R. D. Dillman performed the evaluation of the data processing results. Dr. R. W. Douglass, the project scientist of the Forestry Applications Project, provided constructive criticisms in his review of this paper.

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1. INTRODUCTION

Difficulties have been encountered in recent Land Satellite (Landsat-1) investigations (refs. 1, 2) on the mapping of mixed softwood/hardwood timber stands by computer classification techniques such as the parametric pattern recognition approach (ref. 3) and the nonparametric pattern recognition approach (ref. 4). The salt-and-pepper appearance has been encountered on computer classification maps produced from other resource inventories and agricultural applications (refs. 5, 6, 7). These maps are undesirable to users who would like to clean them up for deriving more usable, smoother resource maps.

In forestry applications, the difficulties in mapping mixed features (i.e., types, classes) and the salt-and-pepper appearance on classification maps seem to be results of common causes: the definition of a basic mapping unit, the size of the unit, and the composition of the unit.

By U.S. Forest Service (USFS) definition (ref. 8), a timber stand is an area larger than 4 hectares (10 acres) that contains a major timber type or major codominant types. A softwood stand is defined as a stand whose canopy contains at least 51 percent softwood trees; a hardwood stand, as one whose canopy contains at least 76 percent hardwood trees. A mixed softwood/hardwood stand is defined as one containing proportions of softwoods and hardwoods in between the homogeneous softwood and the homogeneous hardwood stand type; that is, 26 to 50 percent softwoods and the rest hardwoods.

It is obvious why classification maps of homogeneous timber stands can be heterogeneous, thereby giving salt-and-pepper appearances. That is, the heterogeneity permitted in a defined homogeneous timber stand allows picture elements (pixels) in the

stand to belong to, and consequently get classified into, types other than that of the stand.

The case for defined mixed softwood/hardwood stands is even more complicated. Extraction of spectral signatures for this mixed type (refs. 1, 2) proved to be practically impossible. Furthermore, mixed softwood/hardwood stands were often classified as conglomerates of individual softwood pixels and hardwood pixels even though a mixed signature was used in the classification competing against softwood signatures and hardwood signatures. In those studies, careful ground checking revealed that many USFS-defined mixed stands were not uniformly mixed with softwood and hardwood trees; but rather, they contained small clumps of softwood trees and hardwood trees.

In a recent paper (ref. 9), a new postprocessing algorithm that eliminates connected sets smaller than a prespecified size and merges them to the surrounding area is proposed. Testing on a set of aircraft multispectral scanner data showed the procedure to be successful in removing the spottiness of classification maps. That method was also compared to other existing neighbor-checking postprocessing techniques and was found to be more appropriate for timber stand mapping.

This paper proposes a new approach for resolving the difficulties in mixed stand mapping and for cleaning up spotty classification maps. This new approach is designed to treat mixed softwood/hardwood stands as admixtures of softwood pixels and hardwood pixels. It actually utilizes a modification and iterative application of the postprocessing algorithm cited in reference 9. The procedure was then tested on Landsat-1 multispectral scanner data of the Sam Houston National Forest, Texas.

2. POSTPROCESSING OBJECTIVES

The objectives of the new computer postprocessing approach for forestry applications are two-fold:

- To map mixed forest features; for example, mixed softwood/hardwood stands which are admixtures of small softwood areas and small hardwood areas.
- To clean up the salt-and-pepper spotty appearance of computer classification maps in order to produce more usable, smoother resource maps.

The postprocessing computer program discussed in this paper is designed to operate on computer classification maps such as those obtained by a training field maximum likelihood classification process (ref. 3).

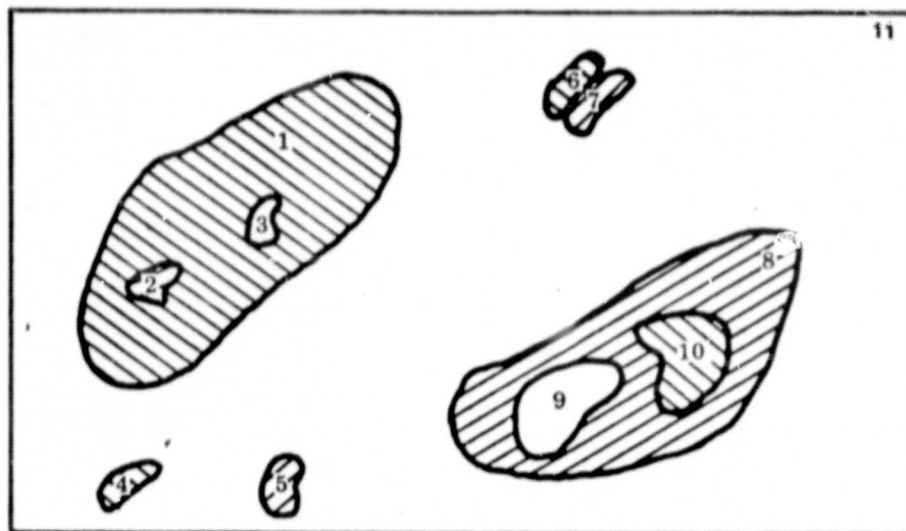
It should be realized that the proposed approach is applicable to all remote sensing data processing other than forestry applications if the mixed features present are similar to the mixed softwood/hardwood features and that the cleaning effect of the approach is valuable to all resource mapping processes.

Figure 1 can be used to illustrate the two objectives. Figure 1(a) is a computer classification map before postprocessing. Figure 1(b) is a desirable final resource map, which should be derivable from figure 1(a) with the application of a well-designed postprocessing procedure.

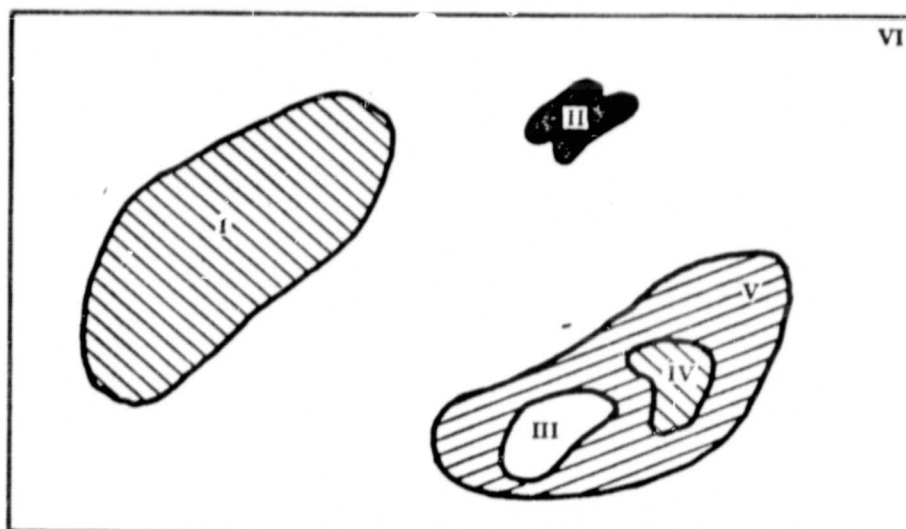
Figure 1(a) is composed of 11 areas, large and small, numbered from 1 to 11. Areas 1, 4, 6, and 10 are classified as softwood; areas 2, 5, 7, and 8 as hardwood. The remaining areas 3, 9, and 11 are designated "others"; that is, nonsoftwood, non-hardwood. Areas 2, 3, 4, 5, 6, and 7 are smaller than

4 hectares (10 acres), whereas areas 1, 8, 9, 10, and 11 are larger than 4 hectares (10 acres).

According to the USFS timber stand minimum requirement of 4 hectares (10 acres), areas 2, 3, 4, and 5 should be cleaned up (i.e., eliminated) and their types changed to that of the surrounding stand. The small softwood area 6 and hardwood area 7 should also be eliminated (in this case, they are adjacent to each other). That is, areas 6 and 7 together form a candidate for a mixed softwood/hardwood stand if the size and composition are proper. Thus, if area 6 covers 2 hectares (5 acres) and area 7 covers 3 hectares (7 acres), the resulting grouping of areas 6 and 7 makes 5 hectares (12 acres) and a 40/60 percent softwood/hardwood mixture. That is, the conglomerate of areas 6 and 7 qualifies and should be mapped as a mixed softwood/hardwood stand. Figure 1(b) with five areas numbered I, II, III, IV, V, and VI should be the desirable final timber stand map. A well-designed postprocessing procedure should be able to transform figure 1(a) to figure 1(b).



(a) Three-class classification maps before postprocessing containing softwood, hardwood, and "others."



(b) Desirable final resource map after postprocessing map in (a), resulting in four classes; namely softwood, hardwood, mixed softwood/hardwood, and "others."

LEGEND





-  SOFTWOOD
-  HARDWOOD
-  "OTHERS"
-  MIXED SOFTWOOD/HARDWOOD

Figure 1. — Computer classification maps.

3. COMPUTER PROGRAM "CLEAN"

A new computer algorithm (CLEAN) that postprocesses binary classification maps (i.e., maps having pixel values of 0 or 1) is proposed in reference 9. Program CLEAN was demonstrated to be able to smooth out the salt-and-pepper appearance of classification maps, thus satisfying the second objective stated in section 2. A binary classification map was considered to be general because any multiclass classification map can be examined one class at a time. Thus, the multiclass map can be reduced into a two-class map consisting of the class of interest and the class not of interest. Modification of the program is also relatively simple to make the program workable directly on multiclass maps.

Program CLEAN is designed to search for connected sets in the binary classification map. The sizes of the connected sets are determined and checked against a prespecified threshold, n_0 . Connected sets smaller than n_0 pixels are eliminated by changing their labels to the other type; that is, small sets of 1's will be modified to 0 labels and 0's to 1's.

A set of pixels is considered connected if every pixel is a left/right or top/bottom neighbor of at least one other pixel in the set; the set of one pixel is also considered connected. Although easily modifiable, diagonal connectivity was not implemented in program CLEAN. The idea of connectivity had been studied by past pattern recognition researchers, but it was never applied in the same fashion as in program CLEAN.

Although the concept is a simple idea, it is rather difficult to program CLEAN efficiently given the usual limited computer core storage. The final design of program CLEAN requires the execution of six basic steps:

1. Input - Input the data to the data array.

2. Tag - Tag the along-the-line connected sets.
3. Cluster - Check across-line connectivity and tag those sets with a common tag.
4. Count - Count the size of clustered tagged sets.
5. Modify - Modify the small connected sets and change the labels.
6. Return - Return to step 1 for more data; otherwise, stop.

The steps call three arrays:

- a. Data array - $A(I,J)$: $I = 1, \dots, n_0$; $J = 1, \dots, N$.
- b. Tag array - $S(I,K,L)$: $I = 1, \dots, n_0$; $K = 1, \dots, N$;
 $L = 1, 2, 3$.
- c. Count array - $C(P,Q)$: $P = 1, \dots, N$; $Q = 1, \dots, 2n_0 + 3$.

In these arrays, n_0 is again the size of the smallest connected set that will not be modified and N is the number of pixels per line in the map. These three arrays occupy $6 n_0 N + 3N$ computer memory spaces (each space is, at most, a computer word).

Program CLEAN was programmed mainly in Fortran on a Univac 1110 computer under the Exec 8 operating system.

4. NEW APPROACH: COMPUTER PROGRAM "GETMIX"

The new computer approach is designed to achieve the two objectives stated in section 2 (to map mixed features and to remove the spotty appearance in classification maps). The approach uses a modification and an iterative application of program CLEAN. The modified program, named GETMIX, again operates on multiclass images treated one class at a time versus the conglomerate of all other classes. Program GETMIX, however, does not modify small sets as CLEAN does. Rather, in any iteration of GETMIX, small sets of the "others" class are eliminated, whereas small sets of the class of interest are retained but have their labels temporarily changed to a new unique label.

This new approach can best be described by the following forestry application. Consider the classification map of figure 2(a), which is identical to figure 1(a) discussed in section 2. The map is comprised of 11 areas, numbered from 1 to 11. Areas 1, 4, 6, and 10 are classified as softwood; areas 2, 5, 7, and 8 as hardwood; and the remaining areas (3, 9, and 11) as "others." Areas 2, 3, 4, 5, 6, and 7 are all smaller than 4 hectares (10 acres). In fact, areas 6 and 7 are 2 hectares (5 acres) and 3 hectares (7 acres), respectively. The other five areas are larger than 4 hectares (10 acres). Assume that the labels for softwood, hardwood, and "others" are 2, 1, and 0, respectively.

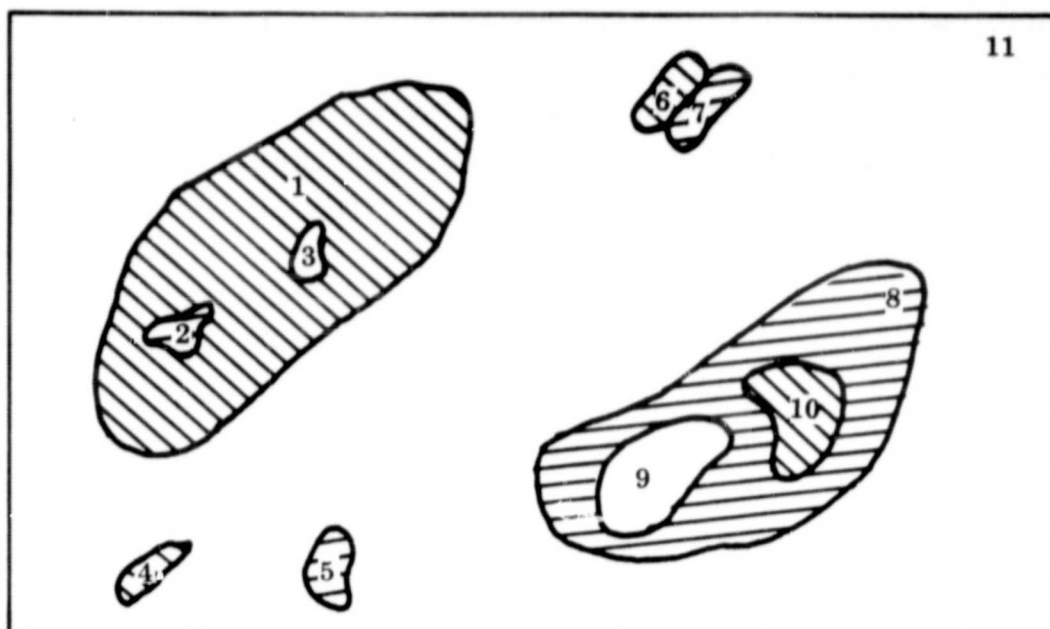
The complete procedure consists of three iterations with program GETMIX. In the first iteration, GETMIX is applied on the class of softwood, labeled 2, with a prespecified value of the program parameter n_0 corresponding to the size of the smallest connected set that is not to be modified; that is, 4 hectares (10 acres). Here, the class of interest is 2, and classes 1 and 0 together make the conglomerate class not of interest. The small areas 2 and 3 in figure 2(a) belonging to the class not of interest are

eliminated; that is, their labels are changed to 2. Note that the small areas 5 and 7 are now embedded in the surrounding area 11 and are considered as part of the class not of interest; hence, areas 5 and 7 are left untouched. On the other hand, small connected sets of class 2 (namely, areas 4 and 6) are retained and temporarily labeled 102. The resulting map is shown in figure 2(b).

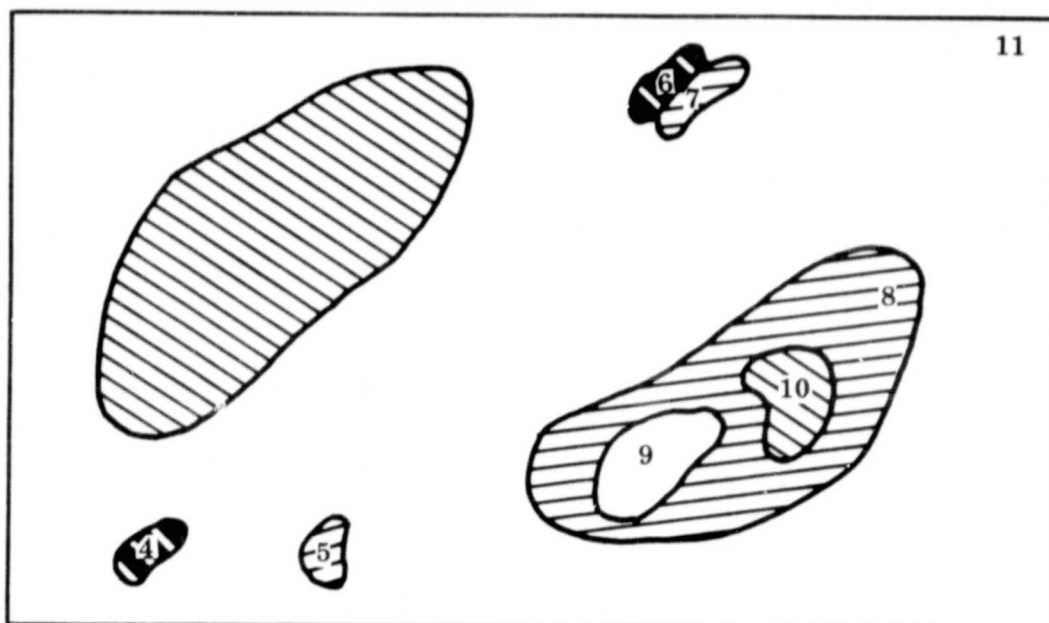
In the second iteration, program GETMIX is applied to the map in figure 2(b) operating on the class of hardwood, labeled 1, using the same value of n_0 corresponding to 4 hectares (10 acres). Here, the class of interest is 1; and classes 2, 0, and 102 together make the conglomerate class not of interest. In the present iteration, there is no small set of the class not of interest by the same argument presented above. Hence, only the small areas 5 and 7 of the class of interest are temporarily relabeled 101. The resulting map is shown in figure 2(c).

In the third iteration, program GETMIX is applied to the map in figure 2(c) operating on the conglomerate class of 101 and 102, using the same value of n_0 corresponding to 4 hectares (10 acres). Here, the class of interest is 101 and/or 102; and classes 2, 1, and 0 together make the conglomerate class not of interest. This iteration takes care of the small isolated sets of 101 and/or 102; that is, the small areas 4 and 5 are eliminated. The large sets of 101 and/or 102 (areas 6 and 7) together constitute a candidate for the mixed stand. After the proportion in this conglomerate of areas 6 and 7 is checked, this area is designated mixed because the areas are 2 and 3 hectares (5 and 7 acres), respectively. The final postprocessed map is shown in figure 2(d). If improper 101/102 mixtures occur, they will be redesignated as 1's or 2's (i.e., hardwood or softwood).

In conclusion, this iterative application of program GETMIX has been shown to produce the desirable final map of figure 2(d) [identical to figure 1(b)] from map of figure 2(a) [identical to figure 1(a)]. It can also be verified that the end result does not depend on the order of application of the first two iterations.

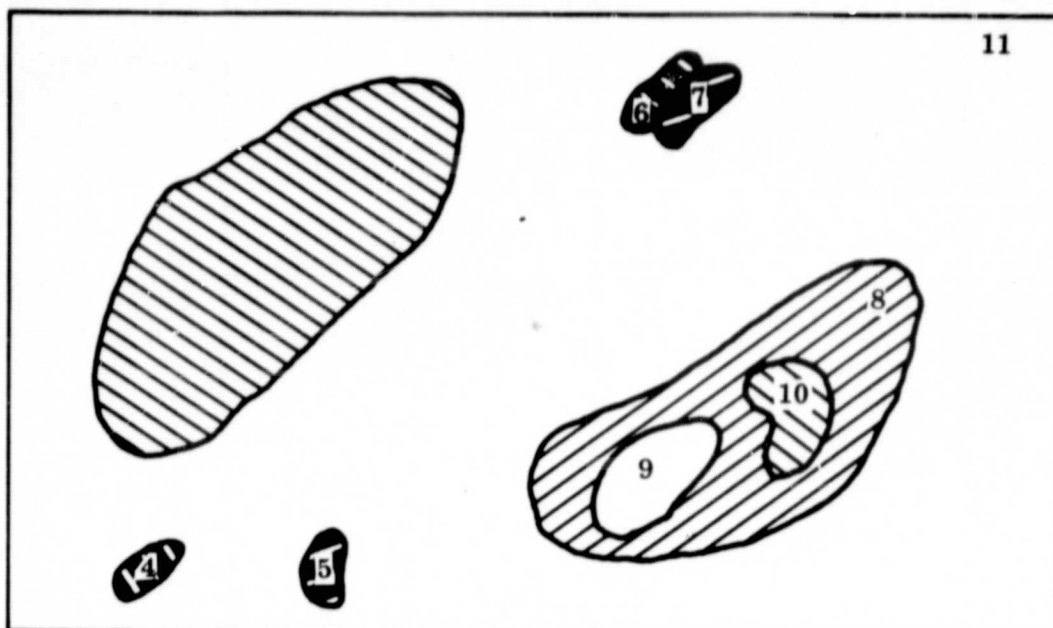


(a) Three-class classification map containing softwood, hardwood, and "others."

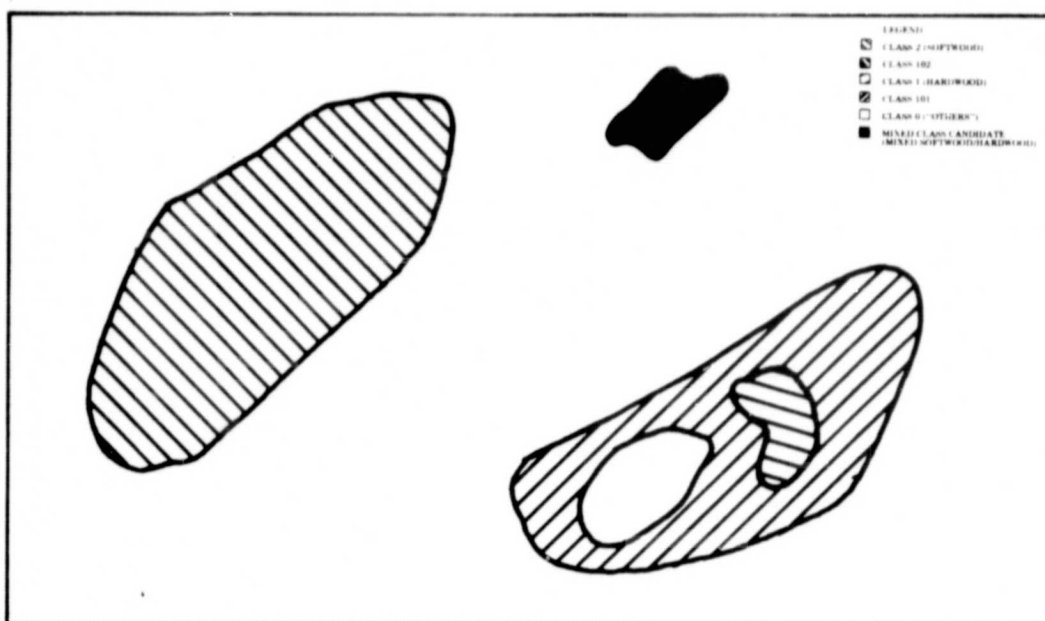


(b) Postprocessed map after first iteration, ISELEC = 2.

Figure 2. — Classification maps obtained by using the program GETMIX.
(ISELEC means class selected for processing; i.e., class of interest.)



(c) Postprocessed map after second iteration, ISELEC = 1.



(d) Final postprocessed map containing softwood, hardwood, mixed softwood/hardwood, and others after third iteration, ISELEC = 101=102

Figure 2. — Concluded.

5. FORESTRY APPLICATIONS

To test, verify, and evaluate the new GETMIX approach on practical applications, the computer program was applied on a set of Landsat-1 multispectral scanner data on the Sam Houston National Forest. The data were a temporal composite of 16 spectral channels covering the four seasons of the year (the summer of 1972 through the spring of 1973). Four best channels were selected by means of standard LARSYS-type (ref. 3) techniques and used in a LARSYS-type classification with two training classes; namely, softwood and hardwood. A three-class classification map containing softwood, hardwood, and "others" was derived. Classification accuracies for softwood and hardwood test areas and training areas on the map were shown to be between 85 and 99 percent (ref. 1). This classification map, shown in figure 3, covers about 500 scan lines, 600 pixels in each scan line, corresponding to approximately 40 by 50 kilometers (25 by 30 miles). The three gray shades are coded as follows: black for "others," medium gray for softwood, and light gray for hardwood.

The program GETMIX was applied to the classification map of figure 3 with $n_0 = 3, 5, 6, 10, 20,$ and 40 , corresponding to the minimum allowable features of 2, 3, 4, 6, 12, and 24 hectares (5, 7, 10, 14, 29, and 59 acres); one pixel of the tested data corresponded to 0.64 hectare (1.58 acres). Results of these postprocessings were similar on the cleaning effect and were logically such that only the larger mixed areas were mapped with larger values of n_0 . The final postprocessed map for $n_0 = 5$ [4 hectares minimum (10 acres)] is shown in figure 4 as a typical example. The four gray shades in figure 4 are coded as follows: black for "others," medium gray for softwood, light gray for hardwood, and white for mixed softwood/hardwood candidates. Figure 5 shows and numbers the location of the 25 mixed candidates.

Mixed stands from the candidates shown in figure 4 can be identified by checking the proportions of softwood and hardwood in the candidates. This checking was not automated in the present GETMIX program; and although programming this step is not complicated, it was not performed because of manpower limitations. In the present study, the classification map after the last but second iteration was also printed (not shown here), from which the compositions of the candidates were readily obtained. By so doing, 8 of the 25 mixed candidates were shown to be truly mixed softwood/hardwood stands that satisfied the proportion requirements; that is, 26 to 50 percent were softwoods and the rest hardwoods. (They are numbered 1 through 8.)

These identified mixed softwood/hardwood areas were then evaluated against two sets of ground truth. The first set, prepared by the USFS National Forest System personnel in 1968, was the timber stand map. The second set, an interpretation by a skilled forester familiar with the Sam Houston National Forest, was made on a color infrared 1:60,000-scale transparency over most of the test area and was acquired during the same spring season covered by the Landsat temporal data. During the interpretation of the second ground truth set, mixed stands were interpreted as being about 50/50 softwood/hardwood areas instead of the stringent 26 to 50 percent requirement on softwoods. This slackening of proportion requirement was considered necessary for the scale of imagery (1:60,000 scale instead of the 1:15,840 and smaller scales used by the USFS and the time allotted for interpretation [4 hours over a 22-by-22 centimeter (9-by-9 in.) frame]. Stereoanalysis was also employed in the interpretation.

In general, the evaluation showed very poor matching of the computer-mapped mixed areas to the ground truth. The USFS stand map showed only one mixed stand in the test area; it had been mapped as area 17 in figure 5. However, area 17 did not satisfy

the proportion requirement of a truly mixed stand on the Landsat classification map. On the second set of ground truth, about 15 percent of the photograph scene was interpreted as mixed areas, as compared to less than 1 percent in the postprocessed map (and even less area on the USFS map). Of the 25 computer-mapped mixed candidates in this scene, only one was categorized in the interpreted mixed area; this is the same area 17 in figure 5 that was labeled mixed by the USFS. Again, area 17 on the Landsat map did not qualify as a truly mixed stand.

In this Landsat analysis, the poor matching between computer-mapped mixed areas and ground truth defined mixed stands can be attributed to the dual reasons of inadequate resolution and inappropriate definition of mixed features. The Landsat multispectral scanner at 60- to 80-meter (198- to 264-foot) resolution observes the whole forest, or parts thereof, in contrast with the 1:60,000-scale imagery that records details of individual trees and their juxtaposition. In Landsat data, the texture of the forest due to its mixed composition is partially, if not completely, obliterated. As a hindsight on Landsat analysis, the definition of mixed softwood/hardwood stands as admixtures of softwood pixels and hardwood pixels seems to be as invalid as the search for signatures of mixed stands by conventional methods because the coarse Landsat data resolution does not permit such a definition of mixed stands and extraction of unique signatures for these stands by conventional methods.

Last, even if the vast discrepancy among the present USFS stand map, the interpreted small-scaled imagery, and the computer-postprocessed map have raised nothing but queries, doubts, and inconclusions on the utility of the computer method, this forestry application has succeeded in stimulating the following thoughts. It is realized that the utility of any map product depends on its ready availability; likewise, the acceptance of

any mapping technique depends on its reliability and repeatability. Because the computer approach is certainly repeatable and nonsubjective and because computer map products are certainly mass-producible, the computer approach seems to be the best mapping approach if it produces reliable and usable results. Now that the USFS mapping technique using large-scaled imagery and ground cruising is an accepted technique, though costly and time-consuming, the small-scaled imagery interpretation approach seems to be replacing it for certain resource planning even though the latter might give different resource information; the difference has been exemplified in the present forest application. It then seems plausible that the present computer approach, although now producing very different results and information from the other two mapping approaches, might be just the solution for the future, given enough additional development, improvement, and testing on appropriate data sources.

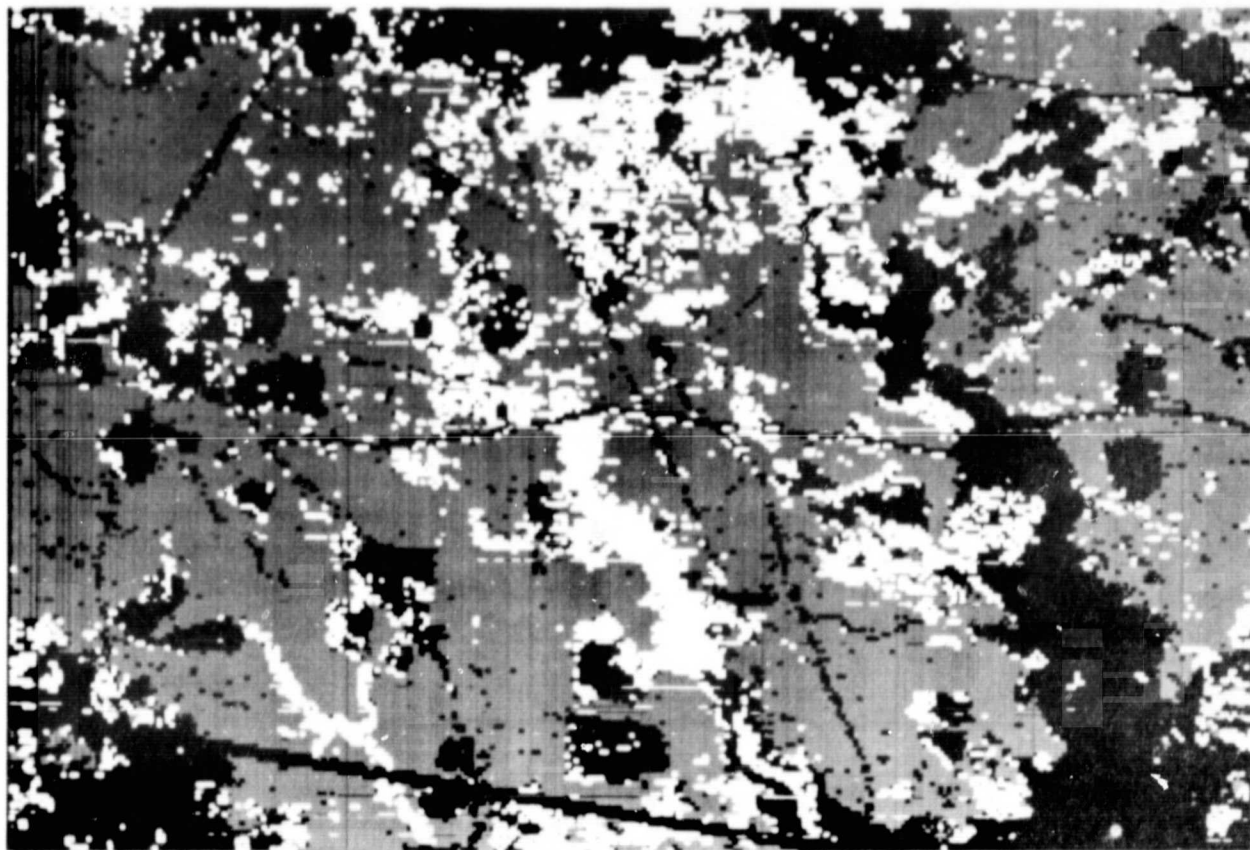


Figure 3. — A three-class classification map of Landsat temporal data on the Sam Houston National Forest. (Black is "others"; medium gray is softwood; light gray is hardwood.)

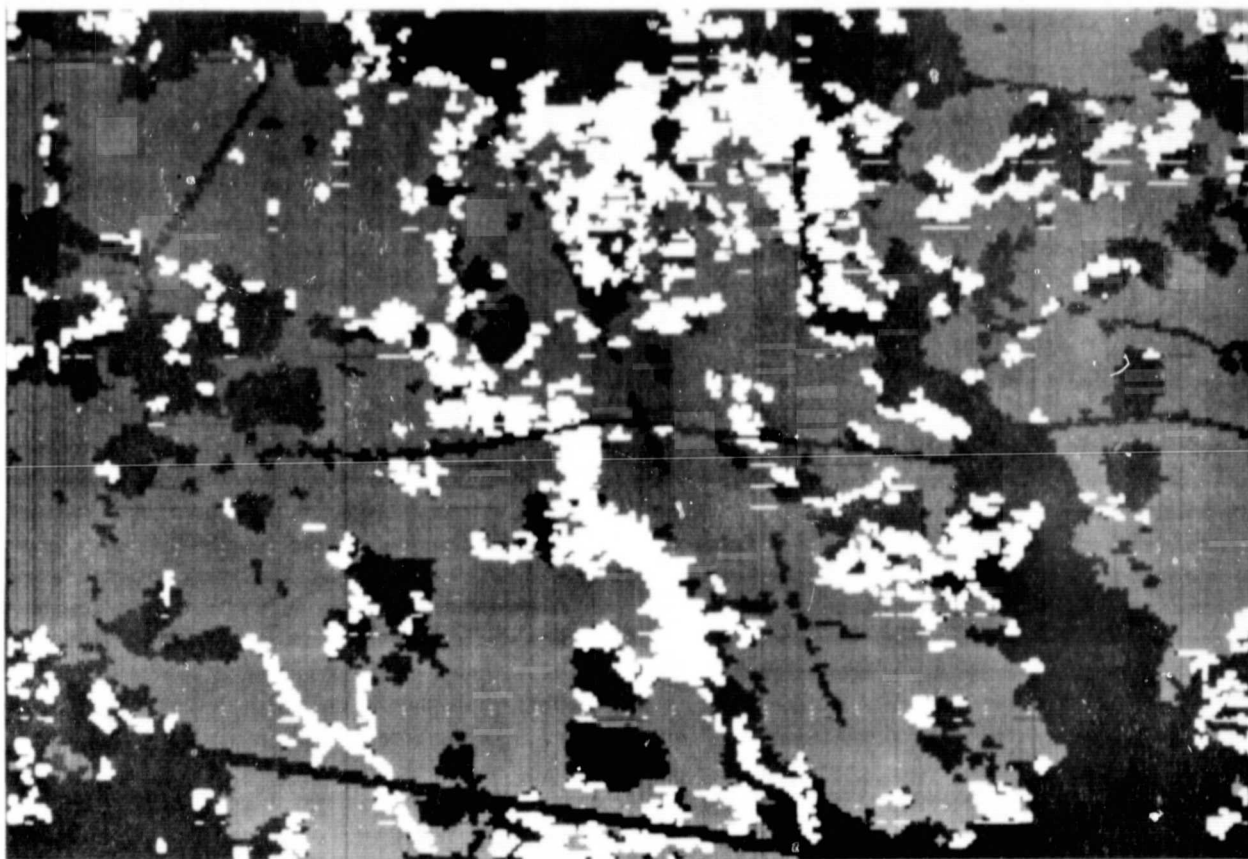


Figure 4. — The postprocessed four-class classification map obtained by applying GETMIX procedure to figure 3 using $n_0 = 6$. (Black is "others"; medium gray is softwood; light gray is hardwood; white is mixed softwood/hardwood candidates.)

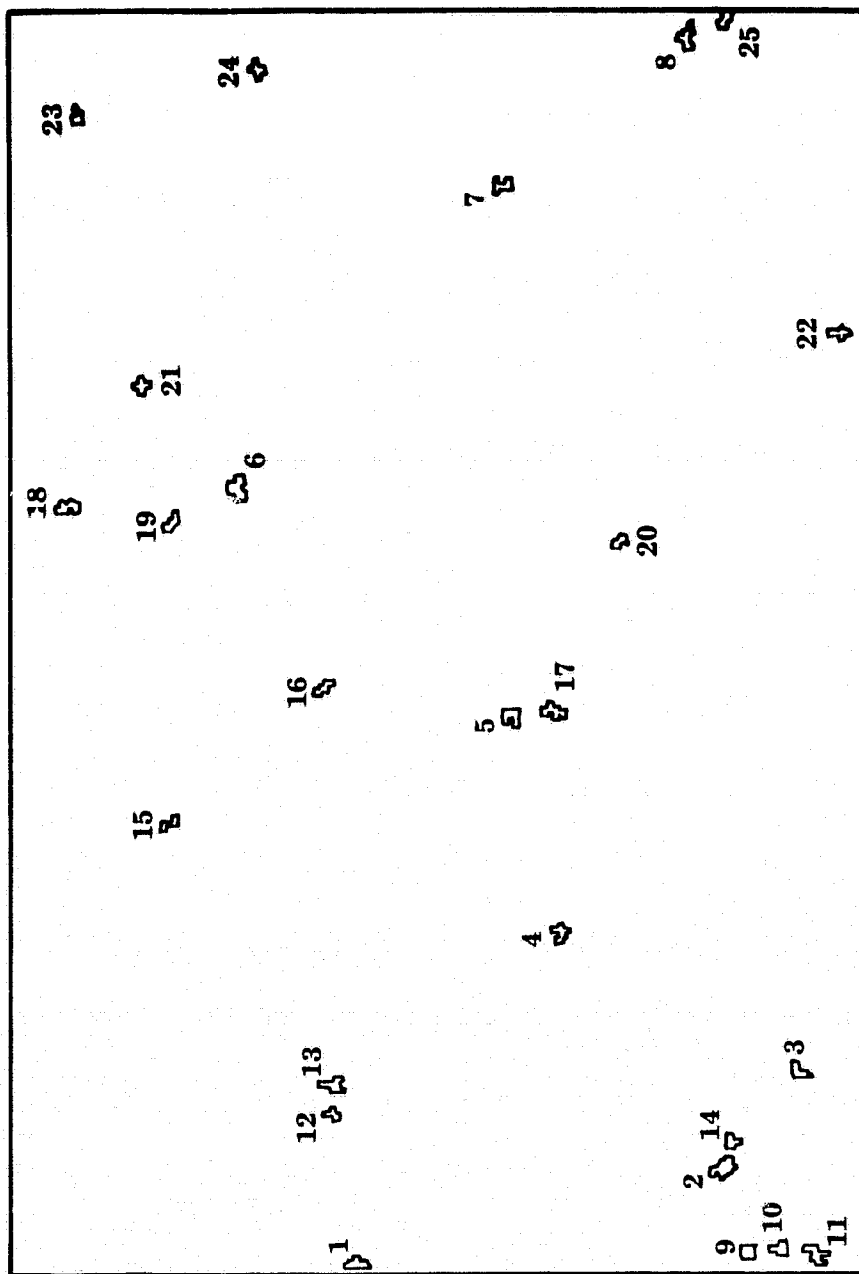


Figure 5. — Map showing and numbering the locations of the mixed softwood/hardwood candidates depicted in figure 4. Areas 1 through 8 constitute true mixed stands that satisfy the proportion requirement.

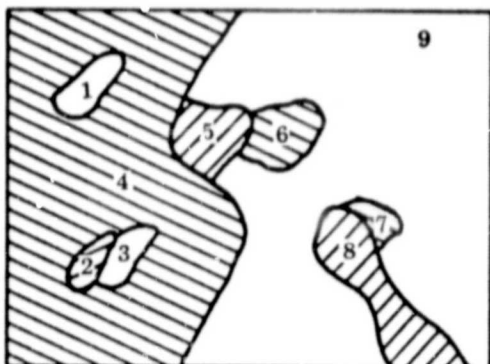
6. AREAS FOR TESTING AND IMPROVEMENT

As mentioned in section 5, the coarseness of the Landsat data resolution causes poor matching of computer-mapped mixed areas to ground truth defined mixed stands. A natural extension of the present work is to apply the proposed method on higher resolution data such as that digitized from the 1:60,000-scale photograph or from Skylab S-190A and S-190B imagery. In fact, processing the digitized data from the 1:60,000-scale photographs would be ideal for testing the present approach, if evaluation is to be performed against the same imagery. In the same light, testing the present approach on aircraft scanner data is recommended as long as radiometric errors, such as scan-angle effects in the data, are corrected or avoided.

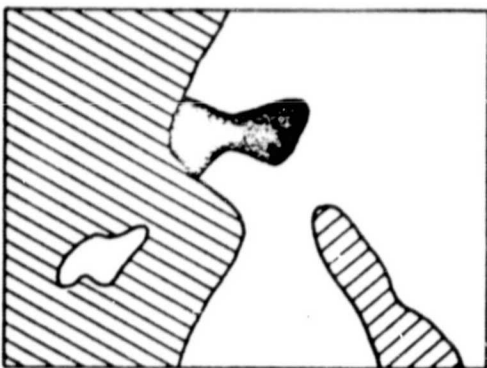
An area that needs further improvement and development is described as follows. With the present design of the program GETMIX, there would be cases in which small areas (e.g., softwood) are modified to "others" instead of being merged to adjacent areas of hardwood. Take the example of figure 6. Figure 6(a) is the three-class classification map containing softwood, hardwood, and "others." Areas 4, 6, and 7 are softwood; 2, 5, and 8 hardwood; and 1, 3, and 9 "others." Areas 1, 2, 3, 5, 6, and 7 are all less than the minimum stand size of 4 hectares (10 acres). However, areas 2 and 3 together are larger than 4 hectares (10 acres); and areas 5 and 6 together are larger than 4 hectares (10 acres).

With the application of program GETMIX as described in section 4, area 1 will be modified into softwood and area 2 into "others"; areas 5 and 6 together constitute a candidate for mixed softwood/hardwood; and area 7 will be modified to "others." The resulting map is shown in figure 6(b). Notice that a natural result by photointerpretation would be the absorption of area 2 into

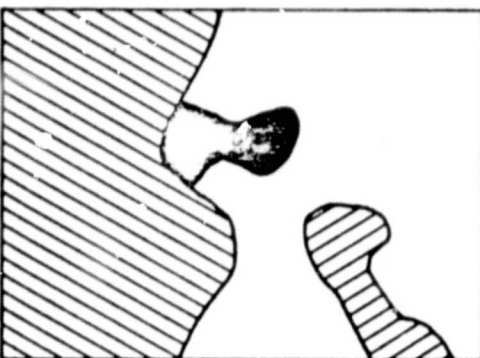
the surrounding area of softwood, then the absorption of area 3 into the surrounding area of softwood, and similarly the absorption of area 7 into the surrounding area of hardwood. The resulting map would be that of figure 6(c). Notice the difference between figures 6(b) and 6(c) in the assignment of areas 2, 3, and 7. This discrepancy is an area for redesign and improvement of the proposed computer approach.



(a) Three-class classification map containing softwood, hardwood, and "others."



(b) Postprocessed map after applying three iterations of GETMIX on figure 6(a).



(c) A natural refinement of figure 6(a) via photointerpretation.

LEGEND





-  SOFTWOOD
-  HARDWOOD
-  "OTHERS"
-  MIXED SOFTWOOD/HARDWOOD

Figure 6. — Classification maps that demonstrate areas for testing and improvement.

7. SUMMARY AND CONCLUSIONS

This paper shows the theory and applications of a new computer approach to postprocess computer classification maps of multispectral data, satisfying two objectives: (a) to map mixed forest features (e.g., mixed softwood/hardwood stands which are admixtures of small softwood areas and small hardwood areas) and (b) to clean up the salt-and-pepper spotty appearance of computer classification maps in order to produce more usable, smoother resource maps. The procedure was developed to solve the problems encountered in earlier studies, in which it was concluded that mapping of mixed forest features such as mixed softwood/hardwood stands was not possible with standard training field pattern recognition approaches. The need for attaining the refinement of maps was already recognized in reference 9.

The proposed iterative approach was applied on a Landsat-1 temporal data set collected on the Sam Houston National Forest of East Texas and classified by standard LARSYS-type techniques. The results verified that the new technique was successful in cleaning the salt-and-pepper appearance of multiclass classification maps and in mapping those mixed softwood/hardwood areas that were admixtures of softwood pixels and hardwood pixels. However, for that particular application, the computer-mapped mixed areas matched very poorly with both sets of ground truth; namely, a USFS stand map prepared 4 years prior to the Landsat coverage and an interpretation by a skilled forester familiar with the test site made on color infrared 1:60,000-scale imagery acquired during the same spring season covered by the Landsat temporal data.

The poor matching, and hence poor performance, of the present approach to map mixed features was attributed to the dual reasons of inadequate resolution and inappropriate definition of mixed

features in Landsat analysis. However, the vast discrepancy between the two sets of ground truth led to the query and hence realization that these information sources are as accurate and reliable as they are intended to be for their specific resource management purposes. Insomuch as they are good sources, their information content would sometimes be incompatible, as exemplified by the discrepancy just stated. The considerations that the computer approach is repeatable and objective and that computer map products are mass producible led to the conjecture that the computer approach would just be the best future approach for certain resource applications, given enough additional development and evaluation. Further testing of the procedure on higher resolution data and avenues for future improvement of the computer design were recommended.

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